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APPLICATION OF COMPUTER AIDED ENGINEERING TECHNIQUES IN COMBINATION WITH HIGH-ENERGY DUST SUPPRESSION TECHNOLOGY FOR THE HANDLING OF COAL

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ABSTRACT: The coal industry faces significant challenges in the control of dust to meet emissions regulations and goals as well as ensuring sustainable operations. This paper describes some of the different techniques and innovative technologies that are being developed and implemented to improve the suppression of airborne dust, specifically through the use numerical modelling in combination with high-energy micro-mist sprays. In the handling of coal, ROM bin loading, transfer points, and discharge to stockpiles are identified as common and significant sources of dust, specific industry examples are presented. To tackle these areas, the utilisation of CFD and CFD-DEM simulation modelling is identified and described as a key enabling technology for an improvement in dust suppression technology both from a level of understanding of the source and dynamics of these emissions, and for the development of new systems that can be used in the coal industry. CFD-DEM modelling is outlined as a method for analysis of dust and air flow, whilst CFD modelling is shown to be effective for modelling spray dispersion and dynamics under varying conditions. New high-energy micro-mist technology is also outlined as a key element in developing high-efficiency dust suppression systems. The application of these technologies is shown as applied to industrial problems at various Australian mines with data presented demonstrating the reduction in dust emissions that can be achieved.

INTRODUCTION

In the coal industry, dust emissions are an increasingly troublesome issue that has seen very little improvement achieved for many years. In Australia, industry emissions of particulate matter less than 10 microns in size has increased from 530 million kilograms in 2009/2010 to 920 million kilograms in 2013/2014, representing a significant and increasing problem (Australian Government - Department of the Environment, 2014). Issues associated with excess dust emissions include health implications, environmental pollution, material loss, and equipment deterioration due to the adverse operating environment. Worker morale and productivity can also be negatively affected by excess workplace dust, and of course, there is the important need to comply with increasingly stringent regulations primarily from a pollution and health perspective. These issues vary with dust properties and concentration, which is directly related to the quantity of material handled and the control methods implemented. Water sprays designed to wet material as a way of limiting dust release is one of the primary methods used for dust control, however, the effectiveness of this method is limited and varies from application to application. Many of these systems also suffer from high consumption of valuable clean water. Improved design methods in combination with high energy micro mist nozzles will be presented in this paper as a means of developing much higher efficiency dust control

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systems with lower rates of water consumption and decreased costs compared to the water spray systems commonly in use today.

In the coal industry, there are numerous handling operations which result in the liberation of hazardous dust particles, these include but are not limited to dump pockets, conveyor transfer points, and stockpile stacker conveyors. The variability associated with these operations due to weather conditions such as wind and rain as well as the variability that can occur with material itself, such as moisture content and tonnage, all combine to make it difficult to develop reliable dust control system for all conditions. To achieve a notable improvement in the control of dust in these areas it is necessary that new technologies be developed, and improved design techniques established. Research conducted at the University of Wollongong has identified two enabling technologies that can result in this improvement; the application of high energy micro mist sprays and the use of Computer Aided Engineering (CAE) techniques, specifically Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM). The benefits and factors effecting the use of high-energy micro-mist sprays has been outlined in a number of previous papers (Roberts & Wypych, 2017), (Roberts & Wypych, 2018), (Roberts, *et al*., 2018). The use of CAE techniques such as CFD, DEM, and coupled CFD-DEM for the prediction of air, dust and mist flow in industrial applications has seen considerable interest of late. A validated model of spray simulation using CFD has been developed specifically for dust suppression purposes (Roberts, *et al*., 2018) and the application of this model presents significant benefits for improving the prediction of dust suppression systems in industry applications. A number of studies have also be completed recently utilising coupled CFD-DEM techniques to predict air and dust flows from bulk material handling operations (Grubler, *et al*., 2018), (Hopkins, *et al*., 2018), (Schulz, *et al*., 2018). In this paper the application of these technologies together will be discussed and successful projects benefiting from their implementation will be presented.

NUMERICAL MODELLING

In many materials handling operations fine dust particles are liberated from the ore stream by displaced air as the material falls or as it impacts with a bin or hopper, the entrained air (laden with fine particles) is often displaced undesirably, resulting in a dispersion of particles in the surrounding areas. The use of DEM coupled with CFD presents the opportunity to model these processes so that the dispersion and flow of air and dust can be predicted. Accurate predictions of these processes will subsequently allow for implementation of more effective dust control measures such as dust suppression sprays or dust extraction systems. Examples of the analysis that can be conducted are shown in Figure 1. In the examples shown in Figure 1, opportunities to improve the processes or ways to implement dust control techniques are immediately evident. Firstly, for the rotary car dumper it is evident that a significant portion of the airflow is forced to the rear side of the hoppers, indicating that a control system should be placed in this region to capture the entrained dust particles. Both dust extraction or dust suppression could be considered here, however, based on the air velocity present (>5 m/s) it would difficult to implement an extraction system that could influence the flow of this air effectively. In this case it is therefore likely that the most suitable control measure would be a dust suppression system using high energy atomising sprays that can both deal with the momentum of the dust cloud and has a sufficiently dense mist to capture the dust particles present. A similar analysis can be undertaken for the truck dump process, in this case the air velocities are somewhat lower in the range of 3-4 m/s and the size and location of most dump pockets such as this make them well suited to dust suppression systems providing full coverage and resistance to the dust flow can be achieved.

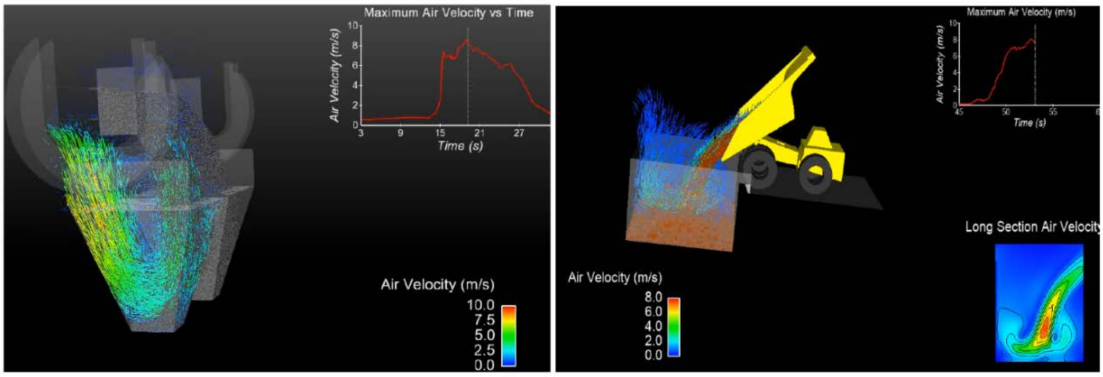

Figure 1: Simulations showing induced airflow from a rotary car dumper (left) and truck dump (right)

In addition to understanding the air and dust flow generated by materials handling activities, numerical modelling of the sprays used for dust suppression can also be pursued and as such the resulting flow dynamics as a combination of the bulk material, airflow, and mist can be studied. This allows for a detailed analysis to be completed during the design process resulting in a more effective system. A technique using ANSYS Fluent and the discrete phase model allows for the fine mist produced by dust suppression sprays to be simulated in a computationally efficient manner. The discrete phase model uses Lagrangian trajectory tracking coupled with a continuous Eulerian phase to model droplets not as free surfaces but as discrete particles moving through the air with drag forces applied per the particle properties and specified drag laws. This technique reduces the need for a very fine mesh and simplifies the model significantly, in turn reducing the computational expense. This method has been shown to accurately predict the deflection and dispersion of sprays in both laboratory and industry conditions. Figure 2 shows an image of an actual spray captured in UOW's mist deflection test rig, and a spray simulated using ANSYS fluent.

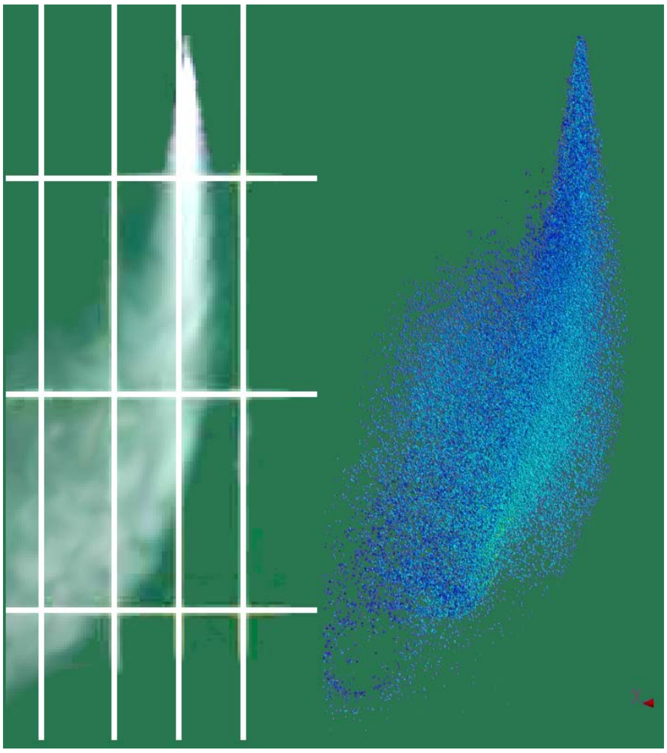

Figure 2: Actual Spray (Left) and Simulated Spray (Right)

Figure 3 demonstrates how a simulation model can be used to understand the flow of mist under varying operating conditions, here the figure is showing how the model predicts the flow of mist for a specific nozzle operated at different pressures. In this case the angle of the spray allows for deflection to be limited, however, as the water pressure increases the amount of mist stripping off the spray cone reduces resulting in more mist impacting the desired region. The use of simulation modelling in this way is particularly important in ensuring that the droplet size distribution and droplet momentum is adequate such that ventilation and/or dust cloud momentum will not adversely affect the performance of any dust suppression system that is installed.

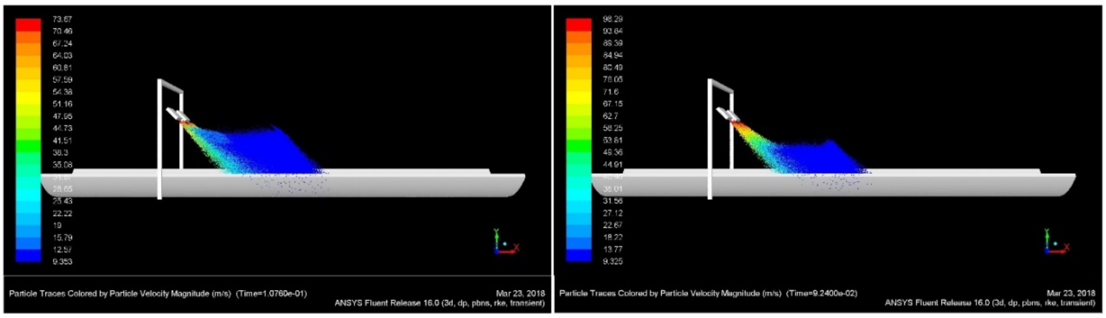

Figure 3: CFD model showing change in mist deflection based on nozzle pressure

APPLICATIONS

It was identified at the outset of this paper that many coal handling operations result in problematic conditions that could benefit from improved dust suppression strategies. It is considered that the application of high energy micro-mist technology in combination with the CAE design approach already described could achieve this. The application of these technologies has the ability to result in a reduction in dust emissions, a reduction in water consumption, reduced design effort, and as such an overall reduction in the costs associated with design and operation of the system.

Utilising this design process, a project was recently completed at a QLD mine having significant issues with dust at the discharge from their rom bin and the transfers at their primary sizer and secondary crusher. An analysis of local airflows utilising CFD-DEM and seasonal weather data allowed for a system to be developed utilising appropriately sized nozzles to adequately capture the dust whilst not being adversely affected by local airflows. The worst case scenario was found when the dump pocket was empty which resulted in large amounts of dust laden air being displaced, with a significant portion of this escaping through the opening for the feeder; this is shown in Figure 4, on the left the opening is clean and empty before the material is dumped, on the right a dust cloud entirely fills the opening and escapes into the air.

Figure 4: Dust escaping through opening for feeder

To suppress the dust escaping at this location, firstly the velocity of the airflow being generated was predicted using coupled CFD-DEM; this is shown in Figure 5, the maximum velocity was approximately 3.5-4 m/s under the expected conditions, this velocity was used for calculation of the correct size sprays for the application based on spray simulations, and mist deflection data previously presented (Roberts, *et al*., 2018). A portion of the installed system is shown in Figure 6; the major dust generating source was from the opening for the feeder and the sprays applied here are shown on the right, dust generated at this point was also carried along the chain feeder and hence sprays were installed along the feeder to capture this, finally the image shows sprays directed into the transfer point to capture dust as it generated by the impact of material onto the sizer. Figure 7 shows dust concentrations measured concurrently with system not running and subsequently with the system turned on at full pressure, both measurements were completed under worst case scenario conditions with a full load dumped into an empty hopper. The average dust concentrations over the periods measured were 10.5 mg/m^3 without the system and 2.01 mg/m^3 with the system on, peak dust concentration reduced from 52.8 mg/m^3 to 5.4 mg/m^3.

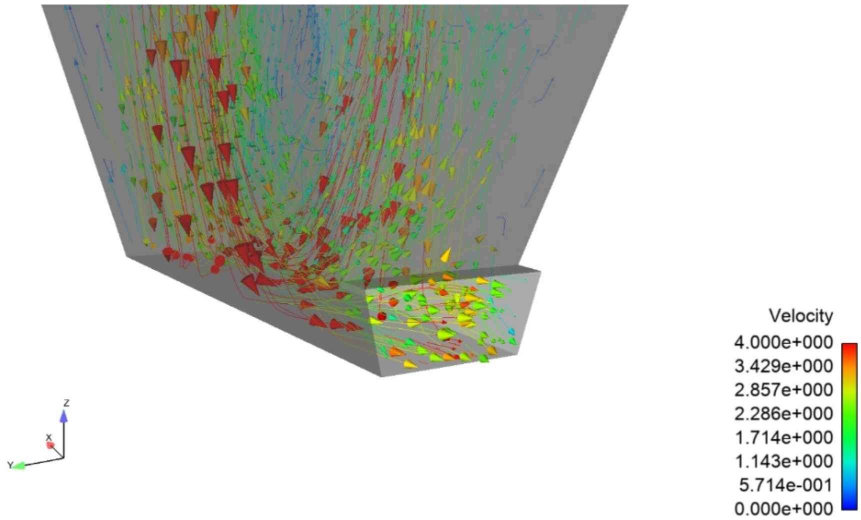

Figure 5: Estimation of velocity of air escaping feeder opening

Figure 6: Installed dust suppression system at exit of hopper, along chain feeder and at transfer from chain feeder to primary sizer

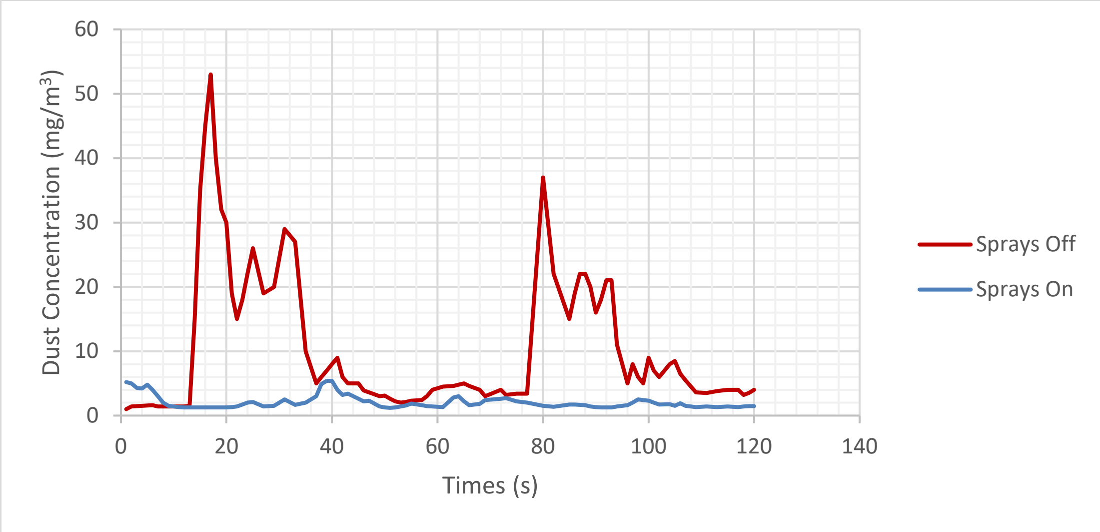

Figure 7: Dust concentration measured with and without the dust suppression system operating

CONCLUSIONS

This paper has outlined the issues associated with excess dust emissions with a specific focus on troublesome areas in the coal industry. High-energy micro-mist nozzles and CAE modelling techniques have been identified as enabling technologies for improving the control and capture of airborne dust. Current systems utilising low concentration coarse droplet sprays or low-velocity air atomising sprays do not provide the dust capture performance required in the adverse conditions present in the coal industry. CFD-DEM modelling has been shown to be valuable as a means of predicting air flow generated during coal handling operations, and CFD modelling of sprays can be used to predict their dispersion. It is evident from the data that was presented from a recent project that a significant improvement in the control of dust in the coal industry can be achieved through the implementation of new high energy micro mist nozzles in combination with these CAE techniques.

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